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(NASA-CR-148497) SEASAT ECONOMIC
ASSESSMENT. VOLUME 4: OCEAN MINING CASE
STUDY AND GENERALIZATION Final Report, Feb.
1974 - Aug. 1975 (ECON, Inc., Princeton,
N.J.) 43 p HC \$4.00

N76-28617

Unclas

CSCL 05C G3/43 15359

VOLUME IV
SEASAT ECONOMIC ASSESSMENT
OCEAN MINING
CASE STUDY AND GENERALIZATION



Report No. 75-125-4B
NINE HUNDRED STATE ROAD
PRINCETON, NEW JERSEY 08540
609 924-8778

FINAL

VOLUME IV
SEASAT ECONOMIC ASSESSMENT
OCEAN MINING
CASE STUDY AND GENERALIZATION

Prepared for
National Aeronautics and Space Administration
Washington, D. C.

Contract No. NASW-2558

August 31, 1975



Note of Transmittal

The SEASAT Economic Assessment was performed for the Special Programs Division, Office of Applications, National Aeronautics and Space Administration, under Contract NASW-2558. The work described in this report began in February 1974 and was completed in August 1975.

The economic studies were performed by a team consisting of Battelle Memorial Institute; the Canada Centre for Remote Sensing; ECON, Inc.; the Jet Propulsion Laboratory; and Ocean Data Systems, Inc. ECON, Inc. was responsible for the planning and management of the economic studies and for the development of the models used in the generalization of the results.

This volume presents a case study and its generalization covering the potential economic benefit of improved ocean condition and weather forecasts to the ocean mining industry. The case study was performed by Edward Sherry of the Jet Propulsion Laboratory, California Institute of Technology. The integration and generalization of the case study was performed by Kenneth Hicks of ECON, Inc.

The SEASAT Users Working Group (now Ocean Dynamics Subcommittee) chaired by John Apel of the National Oceanographic and Atmospheric Administration, served as a valuable source of information and a forum for the review of these studies. Mr. S.W. McCandless, the SEASAT Program Manager, coordinated the activities of the many organizations that participated in these studies into the effective team that obtained the results described in this report.


B.P. Miller

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1. OVERVIEW OF THE ASSESSMENT

This report, consisting of ten volumes, represents the results of the SEASAT Economic Assessment, as completed through August 31, 1975. The individual volumes in this report are:

- Volume I - Summary and Conclusions
- Volume II - The SEASAT System Description and Performance
- Volume III - Offshore Oil and Natural Gas Industry - Case Study and Generalization
- Volume IV - Ocean Mining - Case Study and Generalization
- Volume V - Coastal Zones - Case Study and Generalization
- Volume VI - Arctic Operations - Case Study and Generalization
- Volume VII - Marine Transportation - Case Study and Generalization
- Volume VIII - Ocean Fishing - Case Study and Generalization
- Volume IX - Ports and Harbors - Case Study and Generalization
- Volume X - A Program for the Evaluation of Operational SEASAT System Costs.

Each volume is self-contained and fully documents the results in the study area corresponding to the title. Table 1.1 describes the content of each volume to aid readers in the selection of material that is of specific interest.

The SEASAT Economic Assessment began during Fiscal Year 1975. The objectives of the preliminary economic assessment, conducted during Fiscal Year 1975, were to identify the uses and users of the data that could be produced by an operational SEASAT system and to provide preliminary estimates of the benefits produced by the applications of this

Table 1.1: Content and Organization of the Final Report

Volume No.	Title	Content
I	Summary and Conclusions	A summary of benefits and costs, and a statement of the major findings of the assessment
II	The SEASAT System Description and Performance	A discussion of user requirements, and the system concepts to satisfy these requirements are presented along with a preliminary analysis of the costs of those systems. A description of the plan for the SEASAT data utility studies and a discussion of the preliminary results of the simulation experiments conducted with the objective of quantifying the effects of SEASAT data on numerical forecasting.
III	Offshore Oil and Natural Gas Industry - Case Study and Generalization	The results of case studies which investigate the effects of forecast accuracy on offshore operations in the North Sea, the Celtic Sea, and the Gulf of Mexico are reported. A methodology for generalizing the results to other geographic regions of offshore oil and natural gas exploration and development is described along with an estimate of the worldwide benefits.
IV	Ocean Mining - Case Study and Generalization	The results of a study of the weather sensitive features of the near shore and deep water ocean mining industries are described. Problems with the evaluation of economic benefits for the deep water ocean mining industry are attributed to the relative immaturity and highly proprietary nature of the industry.

Table 1.1: Content and Organization of the Final Report
(continued)

Volume No.	Title	Content
V	Coastal Zones - Case Study and Generalization	The study and generalization deal with the economic losses sustained in the U.S. coastal zones for the purpose of quantitatively establishing economic benefits as a consequence of improving the predictive quality of destructive phenomena in U.S. coastal zones. Improved prediction of hurricane landfall and improved experimental knowledge of hurricane seeding are discussed.
VI	Arctic Operations - Case Study and Generalization	The hypothetical development and transportation of Arctic oil and other resources by ice breaking super tanker to the continental East Coast are discussed. SEASAT data will contribute to a more effective transportation operation through the Arctic ice by reducing transportation costs as a consequence of reduced transit time per voyage.
VII	Marine Transportation - Case Study and Generalization	A discussion of the case studies of the potential use of SEASAT ocean condition data in the improved routing of dry cargo ships and tankers. Resulting forecasts can be useful in routing ships around storms, thereby reducing adverse weather damage, time loss, related operations costs, and occasional catastrophic losses.
VIII	Ocean Fishing - Case Study and Generalization	The potential application of SEASAT data with regard to ocean fisheries is discussed in this case study. Tracking fish populations, indirect assistance in forecasting expected populations and assistance to fishing fleets in avoiding costs incurred due to adverse weather through improved ocean conditions forecasts were investigated.
IX	Ports and Harbors - Case Study and Generalization	The case study and generalization quantify benefits made possible through improved weather forecasting resulting from the integration of SEASAT data into local weather forecasts. The major source of avoidable economic losses from inadequate weather forecasting data was shown to be dependent on local precipitation forecasting.
X	A Program for the Evaluation of Operational SEASAT System Costs	A discussion of the SATIL 2 Program which was developed to assist in the evaluation of the costs of operational SEASAT system alternatives. SATIL 2 enables the assessment of the effects of operational requirements, reliability, and time-phased costs of alternative approaches.

data.* The preliminary economic assessment identified large potential benefits from the use of SEASAT-produced data in the areas of Arctic operations, marine transportation, and offshore oil and natural gas exploration and development.

During Fiscal Year 1976, the effort was directed toward the confirmation of the benefit estimates in the three previously identified major areas of use of SEASAT data, as well as the estimation of benefits in additional application areas. The confirmation of the benefit estimates in the three major areas of application was accomplished by increasing both the extent of user involvement and the depth of each of the studies. Upon completion of this process of estimation, we have concluded that substantial, firm benefits from the use of operational SEASAT data can be obtained in areas that are extensions of current operations such as marine transportation and offshore oil and natural gas exploration and development. Very large potential benefits from the use of SEASAT data are possible in an area of operations that is now in the planning or conceptual stage, namely the transportation of oil, natural gas, and other resources by surface ship in the Arctic regions. In this case, the benefits are dependent upon the rate of development of the resources that are believed to be in the Arctic regions, and also dependent upon the choice of surface transportation over pipelines as the means of moving these resources to the lower

* SEASAT Economic Assessment, ECON, Inc., October 1974.

latitudes. Our studies have also identified that large potential benefits may be possible from the use of SEASAT data in support of ocean fishing operations. However, in this case, the size of the sustainable yield of the ocean remains an unanswered question; thus, a conservative viewpoint concerning the size of the benefit should be adopted until the process of biological replenishment is more completely understood.

With the completion of this second year of the SEASAT Economic Assessment, we conclude that the cumulative gross benefits that may be obtained through the use of data from an operational SEASAT system, to provide improved ocean condition and weather forecasts is in the range of \$859 million to \$2,709 million (\$1975 at a 10 percent discount rate) from civilian activities. These are gross benefits that are attributable exclusively to the use of SEASAT data products and do not include potential benefits from other possible sources of weather and ocean forecasting that may occur in the same period of time. The economic benefits to U.S. military activities from an operational SEASAT system are not included in these estimates. A separate study of U.S. Navy applications has been conducted under the sponsorship of the Navy Environmental Remote Sensing Coordinating and Advisory Committee. The purpose of this Navy study was to determine the stringency of satellite oceanographic measurements necessary to achieve improvements in

military mission effectiveness in areas where benefits are known to exist.* It is currently planned that the Navy will use SEASAT-A data to quantify benefits in military applications areas. A one-time military benefit of approximately \$30 million will be obtained by SEASAT-A, by providing a measurement capability in support of the Department of Defense Mapping, Charting and Geodesy Program.

Preliminary estimates have been made of the costs of an operational SEASAT program that would be capable of producing the data needed to obtain these benefits. The hypothetical operational program used to model the costs of an operational SEASAT system includes SEASAT-A, followed by a number of developmental and operational demonstration flights, with full operational capability commencing in 1985. The cost of the operational SEASAT system through 2000 is estimated to be about \$753 million (\$1975, 0 percent discount rate) which is the equivalent of \$272 million (\$1975) at a 10 percent discount rate. It should be noted that this cost does not include the costs of the program's unique ground data handling equipment needed to process, disseminate or utilize the information produced from SEASAT data. Figures 1.1 and 1.2 illustrate the net cumulative SEASAT exclusive benefit stream (benefits less costs) as a

* "Specifications of Stringency of Satellite Oceanographic Measurements for Improvement of Navy Mission Effectiveness." (Draft Report.) Navy Remote Sensing Coordinating and Advisory Committee, May 1975.

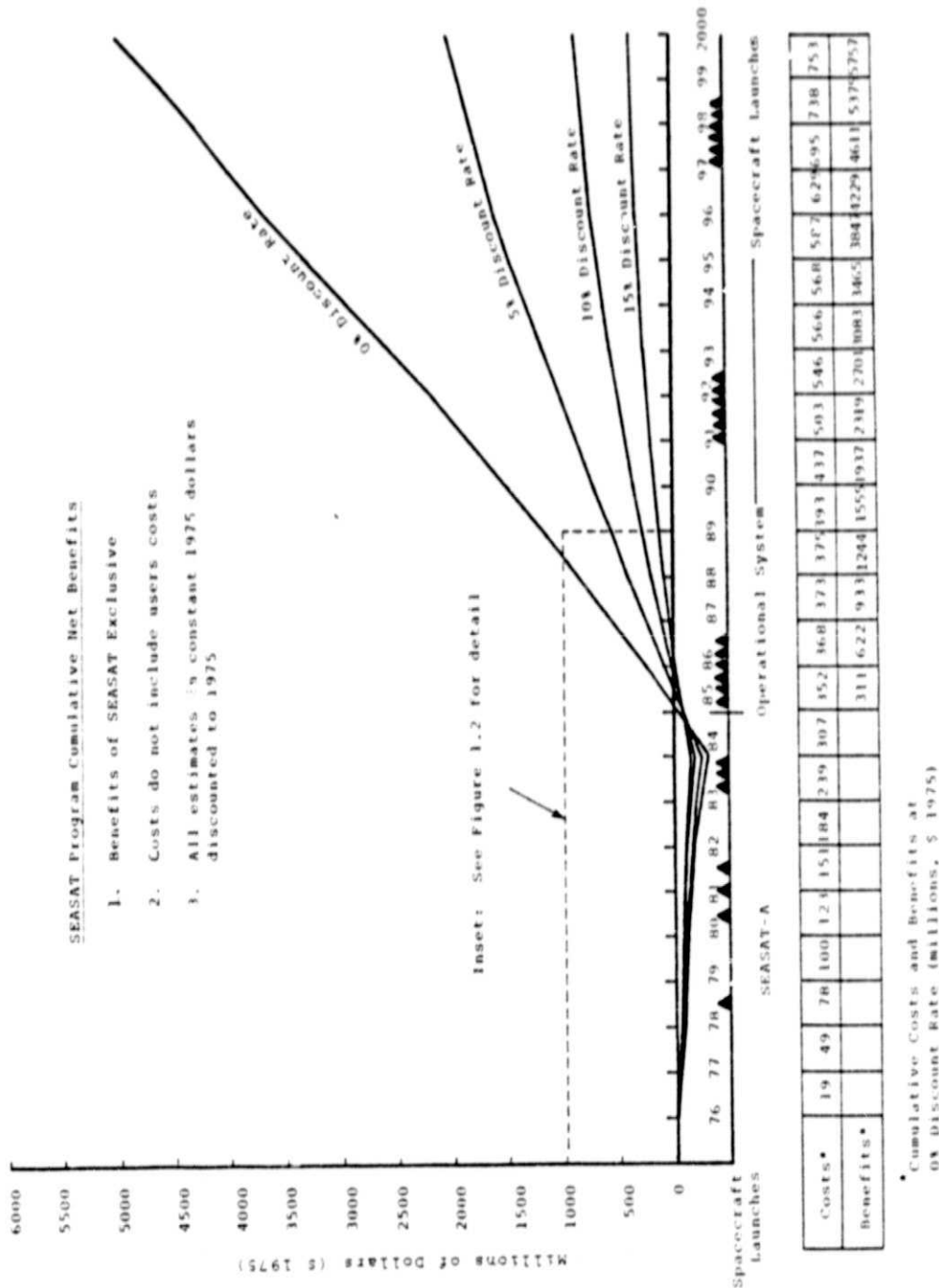


Figure 1.1 SEASAT Program Net Benefits, 1975-2000

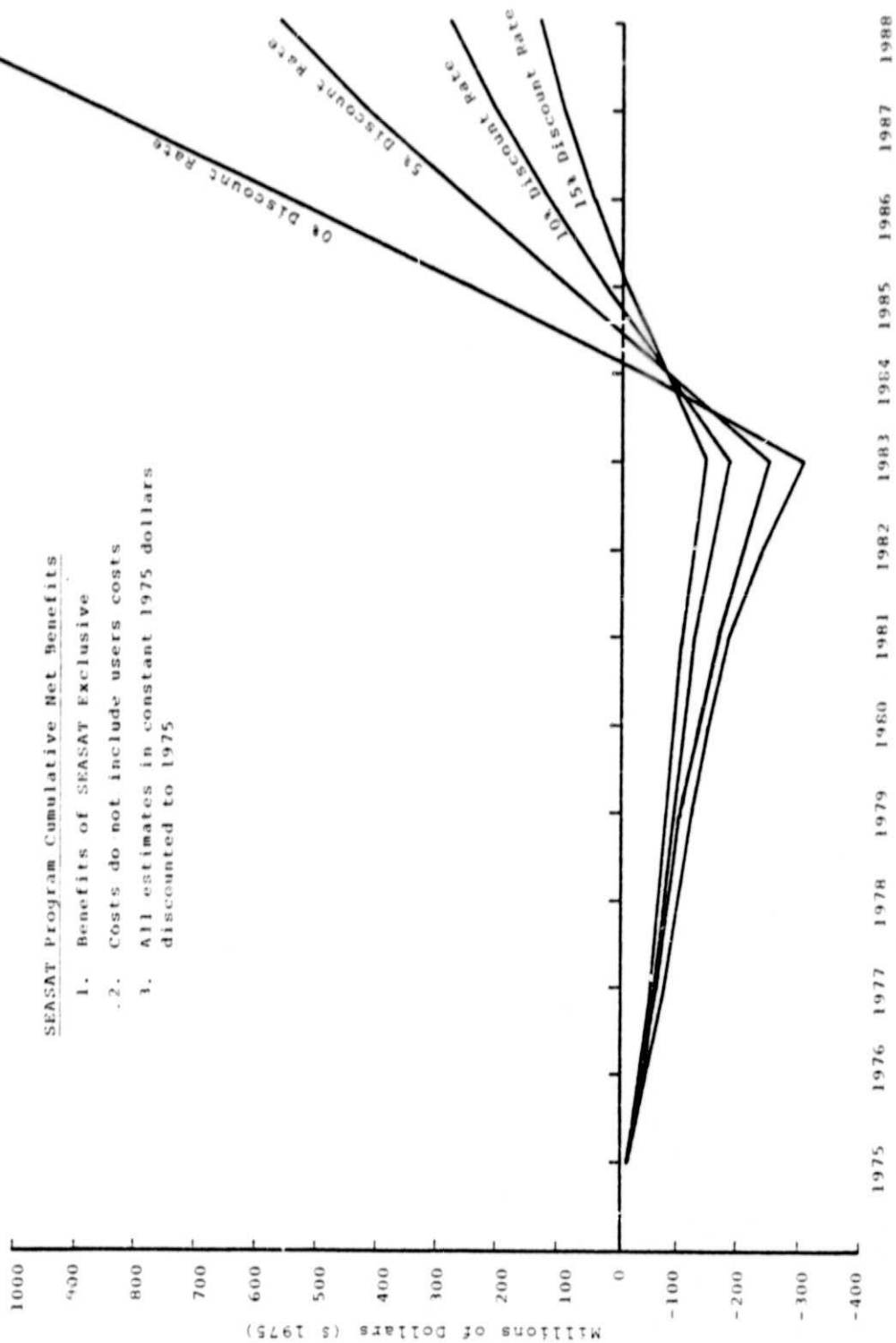


Figure 1.2 SEASAT Program Net Benefits, Inset

function of the discount rate.

This volume describes the results of a case study and its generalization concerning the economic benefit of improved ocean condition and weather forecasts to the ocean mining industry.

2. INTRODUCTION

The surface and subsurface of the ocean bed abound with many natural resources other than oil and natural gas that can be commercially recovered.

The processes of recovery actually employed, or being experimented with, are all either essentially some form of dredging adapted to the depth of water in which the minerals are located or they are strictly mining methods operating through shafts extending into the sea.

Dredging can be performed by three basic techniques. A ladder dredger employs an endless chain of buckets which scoop up the sea bed and generally deposit the dredge into supporting barges. A hopper dredger scoops up the sea bed but deposits the dredge on board the dredging vessel. A suction dredger aspirates, under the influence of a suitable pump, a mixture of water and mineral bearing material which then has to be filtered, to extract the minerals.

Mineral recovery can be undertaken in coastal waters, in estuaries, bays, lagoons, sounds, etc. or the deep ocean can be the site of operations.

In this study, our interest is in operations with minimum dependence on the land. This implies that recovery takes place from ships or special sea-based structures which are operationally dependent on sea conditions and weather at their locations.

Operational dependence implies that the functions of mineral recovery in the ocean have a reduced efficiency because of insufficient knowledge about the sea conditions and the weather at the operating site, which result in avoidable economic losses to the operations. With suitable time intervals of prediction, quality and reliability of information, such avoidable economic losses could be considerably reduced.

Operational dependence is defined by the structure of the operation being considered and by the equipment being employed in the operation. The economic losses that could be avoided may range from complete loss of an expensive and specialized ship to reduction of down-time or nonproductive time by a ship. In order to develop an effective, realistic and credible case study, knowledge of the operations involved and the constraints imposed on the operations by sea and weather conditions must be available. Today many ocean mining activities have operational forms which for competitive reasons are closely guarded secrets. This places a major constraint upon the findings of the case study since the users needs can only either be conjectured or evaluated within a theoretical framework.

Weather and sea condition is currently available for almost any site that can be considered for ore or mining. However, the timeliness, quality and reliability of this information is often deficient, thus causing losses that

could be avoided by improved information. An operational SEASAT system will generate data not currently available which, when combined with other sources of data, will produce both improved local statistical knowledge of weather and sea conditions as well as improved predictions of the expected weather and sea conditions. The former knowledge helps operators in selecting their operating sites, the latter in making a risk decision relating to modifications to their ongoing operations. Risk is always involved where prediction is imperfect.

The case study, reported in this volume, has examined the broad aspects of ocean mining, characterized as near shore and deep sea mining. In each case, however, substantive progress in estimating the benefits of improved information has been hampered by the absence of available operational data from which weather and sea condition dependence could be defined.

3. SUMMARY

The ocean mining industry, in its near shore and deep sea components, conducts various forms of sea bottom dredging most generally from dredger ships.

In general, small numbers of these ships operate in special locations according to the particular minerals sought from the ocean bed.

The ships and the operations that they are engaged in are susceptible to weather and ocean conditions. This fact is evident to the industry operators and some production down-time is always an integral part of the operations.

The dependency of these operations, in particular, production down-time and the form of accidents or other losses that might be incurred, is a closely guarded secret of the industry. It is therefore impossible to obtain data from which benefits from improved weather and sea condition forecasting can be estimated.

Deep sea mining is still very much a formative industry. If this industry is to develop, it must find technical and technological solutions that are efficient for mining and for processing the products from mining. The lack of operational experience limits the derivations of substantive benefits.

The total industry is composed of two basic parts. The first is the near shore mining industry which is well established, quite competitive and, therefore, surrounded by operational data secrecy. The deep sea mining industry is in the process of being created, and therefore lacks operating data. Neither part of the industry lends itself to benefit derivations that can be supported by operational data.

Possible benefits have been derived for near shore mining by dredging based on a tentative suggestion that 5 percent of the current production down-time could be saved by improved forecasting of weather and sea conditions. These benefits are shown below, by industry and location, based on today's operations.

Industry	Location	Annual Benefit (\$ million)
<hr/>		
Tin mining	Thailand, Indonesia	0.74
Sand and Gravel	Great Britain	0.59

In the United States sand and gravel dredging is virtually nonexistent, in spite of the fact that the projected use of sand and gravel in construction is expected to grow by a factor of 2 by 1985 and a factor of 2.5 to 3.6 approximately by 2000. It is expected that the United

States' needs will be filled from onshore or very close to shore operations. Currently, the slowdown in such dredging results from the requirements of the Environmental Protection Agency.*

Generalization of the near shore mining industry tentative benefits has not been attempted because of the difficulty in understanding the future of these industries.

Deep sea mining is currently hardly an industry. It is expected to come into being between 1985 and 2000. Extremely tentative benefits are suggested at about \$3.6 million per year in 1985 and \$7.2 million per year in 2000. Alternatively, this benefit may be stated as \$0.9 million per annum per specialized deep sea mining ship or about 1.5 percent of the capital cost per ship.

The benefits derived cannot be allocated to SEASAT exclusively. However, since dredging equipment and operations are susceptible to wave height and swell, SEASAT will make a significant improvement to forecasting.

* Personal communication. E. Leifleit, U.S. Dredging Corporation, New York, N.Y.

4. CASE STUDY RESULTS

For the purpose of this study, the ocean mining industry was divided into two components; the near shore mining industry and the deep ocean mining industry.

4.1 Near Shore Mining Industry

Considered on a worldwide basis, near shore mining is an active commercial industry with operations conducted in water less than 50 meters in depth.

The following distinctive type of operations exist:

1. Dredging
2. Mining from shafts extending from the land
3. Mining from shafts from ships or platforms
4. Chemical recovery from sea water.

The types of minerals retrieved and the location of the operations are shown in Tables 4.1 and 4.2.

Table 4.1 Minerals Recovered by Dredging	
Minerals	Location
Anagonite	Bahamas
Diamonds	Southwest Africa
Sand and Gravel	Japan, United States, England, Denmark, Holland, Sweden, Iceland
Tin	Thailand, Indonesia
Calcium Carbonate	United States, Bahamas, Iceland, France, Fiji

Table 4.2 Minerals Recovered by Mining		
Operation	Minerals	Location
Mining	Sulphur Barytes (Ba SO ₄)	Louisiana Alaska
Mining Shafts from a. onshore b. artificial islands	Coal Iron Ore	Canada, England, Japan, Taiwan Newfoundland, Finland

Typical minerals commercially extracted from sea water are:

- Magnesium and its compounds
- Sodium chloride and potash
- Bromine and Iodine
- Calcium

as well as fresh water and heavy water.

A global estimate of near shore mining production and value is shown in Table 4.3.

The total value of \$178 million must be used with reserve, as most of the valuation and some production figures have been estimated.

General processes of mineral extraction in 1970 had an estimated value of \$67 million (including quarried minerals). Marine mining above contributed $\frac{178 \times 10^6}{67000 \times 10^6}$ $\times 10^2$ percent or about 0.27 percent of total.

Table 4.3 Near Shore Mining Production and Value

Commodity and Country	Production		% of total offshore production by value	Estimated % of World Production
	Quantity*	Value**		
<u>Sand and Gravel</u>				
United Kingdom	13600	32.0		
Denmark	9500	14.2		
Holland	7800	9.0		
Sweden	1900	2.2		
U.S.A.	5000	6.5		
Others	7200	8.1		
Total	45000	72.0	40.4	<1
<u>Tin***</u>				
Indonesia	10.0	33.0		
Thailand	2.5	8.2		
Total		41.2	26.1	5.8
<u>Calcium Carbonate</u>				
U.S.A.	18000	30.0		
France	276	4.5		
Iceland	125	0.3		
Fiji	79	0.1		
Bahamas	70	0.1		
Total	18800	35.5	19.2	<1
<u>Sulphur</u>				
U.S.A. (6)	1000	25.0	14.0	2.4
<u>Iron Sands</u>				
Japan	N.A.	3.8	2.1	<1
<u>Barytes</u>				
U.S.A.	122	0.8	0.5	3.5
<u>Diamonds</u>				
Southwest Africa	16571 carats	N.A.	----	<1
Totals		178.3	100.0	
*thousand tons **U.S. \$ million ***in concentrates				

Using Table 4.1 with Table 4.3, about $\frac{150}{180}$ or 83 percent of marine minings value comes from dredging or about 0.22 percent of all value from mineral extraction.

Of the near shore marine mining activities, the extraction of minerals from sea water and mining operations appears to be independent of the weather. Thus, any potential benefits to SEASAT will come from dredging operations.

4.1.1 Dredging Operations

These operations are susceptible to sea conditions. For example, ladder type dredgers stop operations when waves are greater than 2.5 feet and the dredgers themselves are vulnerable to waves of from 3-5 feet. Operations are stopped because there is a danger of bending or breaking the spuds which serve to locate the dredge. This type of dredger is also supported by barges to which the dredge products are transferred. The barges are also vulnerable to sea conditions and weather.

Table 4.4 identifies the weather and sea condition magnitudes and occurrence to which dredgers are susceptible in various world locations.

Since dredging activities appear to be the most promising for SEASAT benefits, the various mineral subindustries such as gold, diamonds, tin and sand and gravel, have been examined more closely.

4.1.2 Gold Industry

Dredging for gold in the ocean is in the exploration stage, most activity being in Alaska. The weather

Table 4.4 Dredges, Susceptible Weather and Sea Conditions

Geographical Region	Mining Area	Type of Mineral	% of Year Dredging Operations Closed Due to Weather and Sea Conditions	Wave-Frequency of Occurrence in Days p/yr of Seas Greater than 5 feet*	Swell-Frequency of Occurrence in Days p/yr of Seas Greater than 5 feet*	Tide-Range in feet	Wind-Maximum Knots Wind can achieve at any time	Type of Equipment Used in Dredging Operations
Southeast Asia	Phuket Island, Thailand	Tin	36	27	103	8.5 semidiurnal	27	Conventional bucket-ladder dredge
	Singkep and Bangka, Indonesia	Tin	18	9	57	6.3 diurnal	27	Conventional bucket-ladder dredge
	Bolitang Island, Indonesia	Tin	30	24	85	6.3 diurnal	26	Conventional bucket-ladder dredge
Europe	Thames River region, Britain	Sand and Gravel	27	--	8 to 10 feet swells occur in this area	---	--	Dredge pump with compensating mechanism to maintain suction contact on the sea floor.
Africa	Southwest, Africa	Diamonds (all dredging activities ended in (1971))	75	57	267	5.4 semidiurnal	33	16 or 18" dredge pump w/flexible hose attached through a well compensating mechanism to maintain suction contact on sea floor.
North America	Norton Sound, Alaska	Gold**	50% yr covered w/ice; 25% yr swells over 5 feet	89	183 days of ice	14' above and 3' below mean lower-low water	35	Conventional dredging techniques are impractical.

*The Five foot condition was selected because it represents a limiting state for operation of most conventional dredging and drilling techniques.

**exploration stage

conditions faced in this area are severe, the ships have to contend with ice and high seas.

If this industry matures commercially, SEASAT could be an invaluable aid in helping these ships determine weather and sea conditions. At the present, it is still too early to determine what benefits a satellite could furnish.

4.1.3 Diamond Industry

Presently, there are no commercial dredging operations for diamonds. Most of the diamond dredging was conducted off Southwest Africa, operations ceased in 1971. The main reason for the closure of these various operations was the severe weather and sea conditions in the area. Most dredging operations for diamonds were conducted by ship about 200 miles offshore. For about 275 days of the year weather and sea conditions made commercial dredging practically impossible. The final blow to the industry probably came when two diamond dredging ships were lost in this area because of the weather and sea conditions.

If the diamond dredging industry was revived, an operational SEASAT could be a great asset. The satellite could provide information on weather and sea conditions for these ships.

4.1.4 Tin Industry

Almost all the tin mining dredging operations take place in Southeast Asia. Some of the countries involved are Thailand, Malaya and Indonesia.

The dredging for tin has been going on since the late 1920s. Most of the equipment is not the most modern. The mode of operation is to have several small ships assist a big dredging barge to a particular location. Once the location is determined, the barge will be anchored at that spot. The barge then proceeds to start dredging for tin from the ocean. The barge will remain out for about 18 months. The dredging barge will be anchored in many different spots during this time. The small ships bring supplies and crew change to the bigger barge. The tin dredged from the ocean will be stored in the barge itself. The operation of the barge and the small ships are often affected by the sea state. Most of the worst sea state conditions occur in the winter months due to the monsoon. Some of the possible uses of an operational SEASAT in this operation are as follows:

1. Presently, about 110 days a year in production time are lost to the tin dredging companies because of the bad weather and sea conditions. It has been estimated that the down-time of the barges and other ships could possibly be decreased by 5 percent by use of SEASAT derived forecasts.* SEASAT could provide up-to-date sea state information

* Private communication, M.J. Cruikshank, Ocean Mining Consultant, to E.J. Sherry, Jet Propulsion Laboratory, January 1975.

which could help warn a barge to stay out of a certain area where a storm was going to occur. The barge could then move into another area and resume operations. Thus, more time could possibly be made available to increase production. Also, it is very important to remember that these barges are designed to ride out fairly heavy weather and sea conditions. Thus, the value of 5 percent given for the decreased down-time of the tin barges, because of the updated sea state information made available by use of SEASAT, should be taken as being highly subjective and open to interpretation.

2. In addition, SEASAT data could be used to protect the capital investment in the barge dredging equipment, and smaller supply ships against loss by providing additional lead time in warning of changes in the weather or sea conditions. Information on the capital investment of these various pieces of equipment for the tin industry are kept confidential. This early storm warning data could also result in reduced personal injury and death on board the various ships.*

* Ibid, p. 22.

Overall, SEASAT would appear to directly benefit this particular section of the ocean mining industry. However, the exact value of the benefit is indeterminate at the present time.

4.1.5 Sand and Gravel Industry

A large segment of the sand and gravel dredging operations takes place in England, around the Thames River Region, although commercial dredgers are currently operating in north sea waters.

This industry in Britain has dredging ships that are very up-to-date technologically. The dredging fleets use the most modern equipment possible in their operations, and the ships usually leave their home port daily and return the same night. Their daily average round trip is about 100 miles, dredging along the route while in motion.

The companies who run these ships know the weather and sea conditions affecting their operation. Since most dredging operations are conducted on a daily basis, weather and sea conditions do not tend to disrupt this business. If bad weather occurs, the ship will usually stay in port. If the dredging ships are caught at sea, they are usually close enough to land to seek shelter. Therefore, SEASAT would not appear to benefit them greatly in their daily operations.

Most U.S. commercial sand and gravel dredging by ships operates near the beaches or surf areas of the ocean. For this reason, it is believed that SEASAT will be of little help to the U.S. commercial dredging industry.

4.2 Possible Near Shore Mining Benefits

Possible benefits to the near shore mining industry are estimated on the assumption that improved weather and sea condition forecasting might increase the current production time by 5 percent, by reducing the avoidable down-time for the following operations:

1. Tin mining in Indonesia and Thailand
2. Sand and gravel dredging in Great Britain.

4.2.1 Possible Benefits to Tin Mining in Thailand and Indonesia

Table 4.3 indicates that tin mining production in Indonesia is four times that of Thailand. Table 4.4 shows that production down-time in Thailand, resulting from weather and sea conditions, is 36 percent of the year, and in Indonesia an arithmetic down-time average is 24 percent of the year. Thus, the industry's weighted average down-time is

$$(0.8 \times 0.24) + (0.2 \times 0.36) = 0.264.$$

Table 4.2 identifies the industry value to be \$41.2 million in Indonesia and Thailand.

The value of an industry production day, V, is therefore

$$V = \frac{41.2 \times 10^6}{0.736 \times 365} \text{ dollars,}$$

assuming there is an expected 365 days of production per annum.

With improved forecasting of weather and sea conditions,

it is assumed that production time will be increased by
(0.05 x 0.264 x 365) days.

Thus, the benefit, B, to this industry annually is
estimated to be

$$0.05 \times 0.264 \times 365V = B$$

or

$$B = \frac{0.05 \times 0.264 \times 41.2 \times 10^6}{0.736} ,$$

i.e.,

$$B = \$ 0.74 \times 10^6 .$$

4.2.2 Possible Benefits to Sand and Gravel Dredging in Great Britain

From Table 4.4, 27 percent of the year is lost to
production because of weather and sea conditions that are un-
favorable. From Table 4.3, the industry value in Great Britain
is stated to be \$32 million.

The value of a production day to the industry, assu-
ming 365 days per annum are possible, is W where

$$W = \frac{32 \times 10^6}{0.73 \times 365} \text{ dollars.}$$

With improved forecasting of weather and sea conditions, it is
assumed that production will be increased by (0.05 x 0.27 x 365)
days.

Thus, the benefit, b , to the industry annually is estimated as

$$b = 0.05 \times 0.27 \times 365W$$

$$= \frac{0.05 \times 0.27 \times 32 \times 10^6}{0.73} ,$$

i.e.,
$$b = \$ 0.59 \times 10^6 .$$

4.3 Deep Ocean Mining Industry

This industry is in its formative stage. It is an industry which, at present, concentrates on the recovery of manganese nodules from the sea-bed and the refining of the metals concentrated in the nodules.

A typical high grade nodule deposit is reported to contain in addition to iron, 27 to 30 percent manganese, 1.1 to 1.4 percent nickel, 1.0 to 1.3 percent copper and 0.2 to 0.4 percent cobalt. In addition, there are traces of some 30 other minerals in the nodules, some of which could be detrimental to the production of manganese for steel making, requiring costly separation processes which would significantly reduce the competitiveness of marine resources in comparison with land material.

Because of the vastness of the oceans, exploration has of necessity been limited, and published data on available reserves are highly speculative. Many experts estimate that "billions of tons" of metal can be mined from commercially exploitable marine resources, and one authority states that such

nodule reserves are "in excess of 10 billion tons but less than 500 billion."* Assuming 27.5 percent recovery for all four metals combined would mean total metal content of 2.75 to 140 billion tons. Considering that the corresponding metal content of terrestrial ores consumed in 1973, by the entire world, was less than 20 million tons and that total world reserves on land are estimated at about 1.1 billion tons,** these marine resource figures, however tentative and probably exaggerated, appear to be quite significant.

The nodule-beds, considered most favorable for economic exploitation from the standpoint of both weather conditions and grade of ore, are located in some 15,000 feet of water along an equatorial belt of the Pacific Ocean southeast of Hawaii. "The richest deposits occur in a narrow band, perhaps 200 km across and 1500 km long, running roughly east-west around 9 degrees latitude. Not only are the nodules in this band high in copper and nickel content but they are also very abundant."*** Many other areas in both the north Pacific and the Atlantic

* J. L. Mero. "Potential Economic Value of Ocean Floor Manganese Nodule Deposits." (Paper from a conference on Ferro-manganese deposits.) Ed. D. R. Horn, Arden House and Lamont Laboratory, Columbia University. January 20-22, 1972, p. 202.

** Of this total, 0.37 billion tons represent copper, 0.69 manganese, 0.05 nickel and 0.003 cobalt. Corresponding marine resource estimates, based on 2.75 billion tons are: 0.100, 2.500, 0.125 and 0.025 billion tons.

*** Hammond, loc. cit.

Ocean also contain high grade deposits but, owing to more favorable sea-bed surfaces and climatic conditions, the South Pacific locations appear to be the most promising for initial exploitation.

Of the four U.S. companies (two are joint ventures with foreign firms) active in this field, only Summa Corporation is believed to be engaged in actual mining, probably on a pilot scale. The others have confined their activities to exploration of the sea-bed, adaptation of existing technologies to deep ocean mining, experimental processing of nodule materials, and related engineering and economic studies. As of February 1974, total cumulative investment or firm commitment to invest in nodule mining and related activities is estimated at about \$180 million. Of this total, probably 55 percent may be allocated to the Summa Corporation, 28 percent to Kennecott and its foreign partner, 11 percent to Deepsea Ventures, Inc. and the remainder to Ocean Resources, Inc. and its foreign partners. Various tonnages have been brought up for analysis and experimental processing; two of the companies alone were reported to have dredged 450 tons of nodules by the middle of 1973.* A

* J. E. Flipse and R. J. Greenwald (Deepsea Ventures, Inc.) and M. A. Dubs (Kennecott Copper Corporation). "Background Information to Describe Typical Phases and Activities of Commercial Ocean Mining Development Program." A paper on mineral resources of deep sea-beds. Hearings of Subcommittee on Minerals on Senate Bill S. 1134, May 17, June 14, 15, 18 and 19, 1973, pp. 202, 203.

great deal of knowledge has been accumulated with respect to location of high grade nodules, design of mining machinery and development of ore-processing technology. The last has involved experimentation with at least four separate processes, of which selective leaching by ammonia appears to be particularly promising, and Kennecott is believed to be planning to use this method in a commercial-scale processing plant.

While the major share of total effort has been expanded by U.S. firms, four additional foreign corporations (Canadian, Japanese, German and French) have shown considerable interest; three have worked to improve extractive methods and have operated exploration vessels, and International Nickel has supported research in nodule processing technology and engineering systems studies, in addition to carrying on several exploration cruises on chartered research vessels.

From preliminary examination of recent literature concerning technological achievements over the past decade it may be concluded that:

1. At least one U.S. company (Summa) has invested substantial effort in the development of mining technology.
2. Significant advances have been made in nodule processing technology, with two firms proceeding towards the design of full-scale units.
3. Most of the companies have delineated ocean mining sites considered suitable for commercial operation.

If the criterion of value is commercially marketed output, the current value of marine manganese exploitation may be said to be negligible. On the other hand, the likelihood of early development of commercial operations seems fairly high. Both Deepsea Ventures and Kennecott have gathered substantial quantities of nodules for experimental purposes, and now Summa appears to be doing the same on a much larger scale. The Summa goal, it is reported, is to mine some 3 to 4 million tons of nodules annually. Kennecott is expecting to recover some 3 million tons and Deepsea Ventures contemplates an annual recovery of about 1 million. Thus, in total, U.S. firms could within relatively few years be recovering about 7 million tons annually (dry-weight basis) or perhaps more, if Ocean Resources is able to get into early action.

Deepsea Ventures' lower total recovery goal is related to its intention to extract all four of the principal contained metals (nickel, copper, cobalt and manganese) from the ore, while Kennecott seems to prefer processes which isolate only the nickel, copper and cobalt. Summa has given no indication of its extraction plans but is reported to be contemplating marketing the nodules to others--perhaps Kennecott--for processing.

The scale of activity that will actually develop over the next few years is highly dependent on the outcome of the current Law of The Sea Conference in Geneva and/or on possible passage of interim U.S. legislation regarding deep sea mining. It is also dependent on the details of leasing concessions which

may be granted either under U.S. or international law, or both. It is generally believed that Summa, being less dependent on external financing than are the other contenders, is ready to proceed to commercial-scale mining without the benefit of any new legal protection, instead relying solely on the present doctrine of "freedom of the seas" or possibly the 1958 principle that national rights extend to the limits of technical feasibility. The other active participants have indicated a prior need for protection or guarantees of indemnity against the loss of continuing mining rights.

4.3.1 Present Deep Ocean Mining Activity at Sea

Current sea-going activity, which is mostly located in the region to the southeast of Hawaii, consists of surveying and sampling of nodule deposits.

The deposits are being surveyed in some 17,000 feet of water using low light television cameras to inspect and determine the nodule density and the associated depth of sediment. The German research vessel *Valdivia* is currently so engaged* and is using a 70 mm deep sea photographic camera to photograph areas of specific interest.

Oceanus, Spring 1975, in an article entitled "TV in Deep Ocean Surveys", identifies continuous sea floor scanning with the towing and control of a device on a long cable as being a very complex and delicate operation. At the present, survey speeds are limited to 2 knots or less when a deep-towed package

* Offshore, May 1975, p. 248.

is involved. For example, a survey in 4500 meters of water would require roughly 6000 meters of cable to keep the sea floor in view at a speed of approximately 2 knots. The forces acting on the cable are not constant because of changes in ship motion and path of travel, current regimen, etc. Therefore, the amount of cable extended must compensate for these factors as well as changes in sea floor relief. Turning a ship while surveying requires close coordination between the bridge and the survey party. The rate of turn is typically from 2 to 3 degrees per minute (a 90-degree turn takes between 30 and 45 minutes). Throughout the maneuver the winch operator must be certain the TV does not impact the sea floor and permit the cable to go slack. The choice of direction of survey is determined by prevailing sea conditions and ship limitations. Usually a hitch point at the stern provides maximum latitude but other locations are used, including attachment through a well or "moon pool" in the hull. There are advantages and disadvantages to each type of installation. At best, all are a compromise in respect to other ship capabilities and limitations.

It is most important in detail surveying to know where an observation is made. In general terms, a towed-TV system is approximately 50 to 60 minutes behind the location of the ship but, again, not necessarily directly behind it. With some 5000 meters of cable extended, the system could be well to either side of the path of the ship. This problem is solved by using a complex bottom acoustical navigation system but for general surveying purposes, such a system is impractical.

It is evident, therefore, that current survey activity could be quite susceptible to weather and sea conditions, and that survey speed and development could be aided by weather and sea condition forecasting. In addition, it appears reasonable to assume that both exploratory sampling and later production development will also be dependent on weather and sea condition forecasting. It is clear that weather and sea conditions are important since activity is taking place in regions where these conditions are relatively benign. By coincidence, the nodule deposits are apparently also rich in this region.

There is, however, no experience in deep sea mining from which data could be extracted that could permit the realistic development of appropriate benefits. The corporations involved in this activity are generally secretive about their operating experience, and claim that weather is, at this time, of little importance. Hence, no benefit development from SEASAT data is possible at this time, given the lack of uncertainty of this industry.

4.3.2 Tentative Suggestions of the Benefits that May Be Possible from Deep Ocean Mining

As indicated in the previous section, firm benefits cannot be developed because of a lack of operating data. However, it is possible to estimate, based on current available data from studies, some possible potential measure of benefits.

A recently completed study based on manganese nodule metals, supply, demand, costs and prices, refining and mining technology suggests that U.S. corporations involved may mine by 1985 some 7 million tons of nodules and by 2000 a reasonable output would be 14 million tons of nodules.* It is also suggested that worldwide corporations involved may double this nodule production so that by 1985 perhaps a total mining activity may be producing 14 million tons of nodules, and by 2000, 28 million tons of nodules.

In the same study, at 1973 prices, the 1935 recovery of 7 million tons of nodules is estimated to have a gross value of \$534 million of which \$180 million is within marine mining and the remainder is in onshore processing and refining. Thus, the value of the marine mining part of this study can be estimated as

	1985 value	2000 value
United States only	\$180 million	\$360 million
Worldwide	\$360 million	\$720 million

* "The Economic Value of Ocean Resources to the United States." Prepared for use of the Committee on Commerce in December 1974, pursuant to S. Res. 222. National Ocean Policy study, Chapter 4 - Manganese Nodules, pp. 18-28.

Summa's \$60 million nodule dredge, Glomar Explorer, is believed to have a mining capacity of 5000 tons of nodules per day which is considered to be the minimum size for a commercial operation.* Thus, an estimate can be made of the total mining fleet that may emerge in the future. By 1985 the number of specialized ships from worldwide corporations can be determined as follows. If 14 million tons of nodules are mined, the number of mining production days, P, will be approximately

$$P = \frac{14 \times 10^6}{5 \times 10^3} = 2.8 \times 10^3 .$$

Assuming 365 days of production operation per annum, this implies about eight specialized mining ships in operation. By 2000, the number may double to 16 specialized ships.

The dredging down-time improvement for tin and sand and gravel dredging is about 1 percent of the production time. If this is appropriate to deep sea mining operations, a very preliminary estimate of the worldwide benefit may be about \$3.6 million in 1985 and \$7.2 million in 2000. Based on this estimate, the annual benefit per specialized ship, from improved weather and sea condition forecasting, is approximately \$0.9 million per ship operating which is about 1.5 percent of the current capital cost of each ship.

While benefits to ocean mining have been estimated in this case study, it is emphasized that the parameters used

* Business Week, October 19, 1974.

to derive the benefits are. at best, tentative, and for deep sea mining the benefits are speculative since the manner of development of the seep sea mining industry is conjectural at this time.